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(54) Radiating coaxial cable with improved water-blocking characteristics.

(57) A radiating cable of the foam dielectric type is provided with improved water-blocking characteristics by provision of a barrier tape between an apertured, corrugated outer conductor and the external jacket surrounding the conductor. The barrier tape is wrapped around the outer conductor is such a away as to completely cover the radiating apertures disposed thereupon. The barrier tape is composed of a hygroscopic material which is highly water absorbent and swells up in contact with any water penetrating the cable so as to form a barrier around the aperture conductor, thereby preventing ingress of water into the apertures of the conductor. The barrier tape is particularly effective in restricting longitudinal migration of water by retaining water that contacts the tape in a high localized fashion. The improved radiating cable construction is particularly adapted to be used in conjunction with a layer of fire-retardant tape disposed over the water-blocking tape to realize a cable which is highly resistant to both water and fire and yet is economical and easy to manufacture and use.

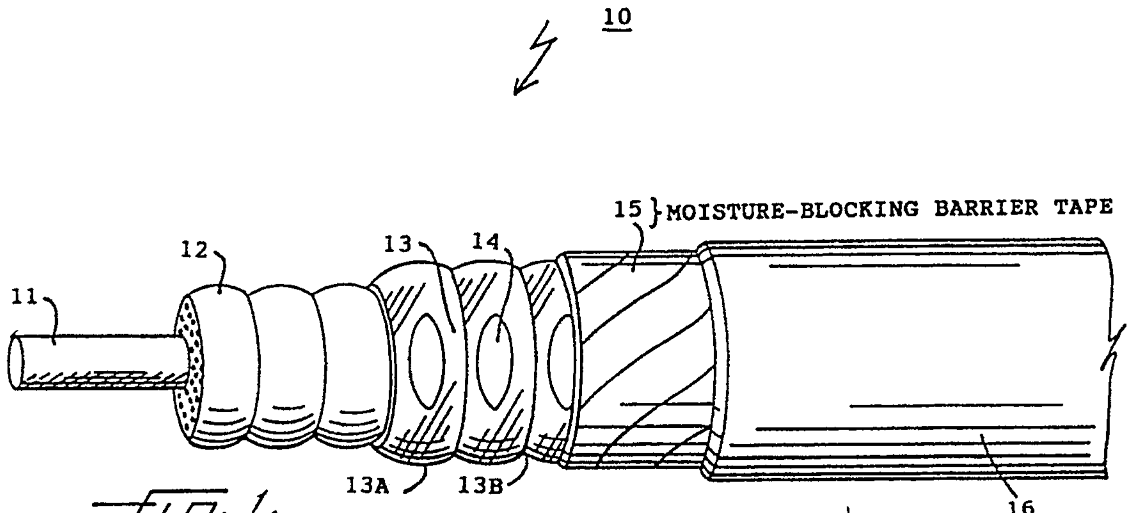

Fig. 1.

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RADIATING COAXIAL CABLE WITH IMPROVED WATER-BLOCKING CHARACTERISTICS

FIELD OF THE INVENTION

The present invention generally relates to coaxial cables for use with communication systems. More particularly, this invention relates to radiating coaxial electric cables formed with foam dielectric material and which exhibit improved water-blocking characteristics.

BACKGROUND OF THE INVENTION

The use of coaxial cables of either the foam or air dielectric type is widespread for antenna feeding arrangements in communication systems. Typical applications include antenna systems for terrestrial microwave systems, cellular and land mobile radio, broadcast transmitting antenna systems, earth-station antenna systems, and high-frequency communication systems. Such coaxial cables function essentially to transmit electrical signals from a generating station to some form of antenna from where the signals are radiated. Coaxial cables of the radiating kind, on the other hand, are designed to themselves functions as continuous antennas so that electrical or radio signals are transmitted directly from the cables rather than from an antenna. Such radiating or "leaky" coaxial cables serve as efficient and economical sources for transmitting radio signals where the use of conventional antennas is impractical. Radiating cable systems are particularly indispensable in two-way mobile radio, radio paging and other localized broadcasting services in applications involving extended underground installations such as railways, mines and tunnels where conventional centralized VHF and UHF communications systems are not practical.

A common problem associated with power transmission cables in general, and coaxial cables in particular, is the substantial deterioration of transmission characteristics due to penetration of water into the cable. Such cables are particularly susceptible when positioned in high humidity environments. Water penetration can seriously impair the electrical and mechanical properties that are critical to continued operation. In particular, the presence of water between insulated conductors within a cable can significantly increase cable capacitance and can, among other things, lead to electrical leakage pathways. Water penetration into the area between insulated cable conductors and the outer sheath can also increase signal attenuation, noise and the possibility of conductor corrosion.

Thus, an important requirement of coaxial cable in many applications is a high retardancy to water or moisture penetration. Even if some water does enter the cable as a result of radial penetration, it is important that any migration of water from the point of damage along the longitudinal axis of the cable be restricted. Prohibiting this longitudinal migration is critical in restricting the degradation of electrical characteristics and cable repair length even if some water penetration does occur as a result of unavoidable outside influences, such as cutting or tearing of the outer cable jacket.

The conventional approach for tackling water penetration in telecommunication and power cables, particularly radiating coaxial cables, has been the use of a variety of highly viscous filling/flooding compounds such as petroleum jelly, Aqualocko®, Teleflock®, etc. for filling up the empty space between the outer conductor and the surrounding protective sheath or jacket. The filling compound is typically pumped into the interior free spaces of cables and, if evenly distributed longitudinally across the cables, serves as an effective water-blocking layer.

However, this flooding approach is complicated and costly in practice because the application of the flooding compound is difficult and time consuming. It is hard to maintain a uniform distribution of the flooding compound along extended cable lengths - if the flooding compound is not applied uniformly, it falls short of being fully effective as a water-blocking layer. In addition, filling cables with the flooding compound in situ during the cable laying operation is cumbersome, messy and constitutes a fairly skilled operation. Further, because of its viscous nature, the blocking compound cannot be thereafter removed easily from the cable, thereby making splicing of cables impractical.

A major problem associated with the use of flooding compounds for according moisture-blocking capability to coaxial cables is that these compounds typically degrade the fire-retardant properties of the cables.

In a variety of power-transmission and telecommunication applications, it is also required that coaxial cables have high retardancy to flame propagation. Over-heating of cables when subjected to current overloads or related system failures can initiate fires. More importantly, when electrical equipment has already been subjected to fire, the cables used therein may themselves contribute to flame propagation and also produce noxious fumes and smoke.

Coaxial cables have been afforded flame retardant properties by sheathing cables with halogen-containing materials such as polyvinyl chloride

(PVC) or other flouroplastic materials. Such cables resist fire propagation even under severe heat conditions; however, upon being exposed to fire the halogen containing materials in the sheaths generate noxious smoke and form toxic and corrosive gases. Flame retardant cables having cable jackets based on crosslinkable halogen free compositions and other inherently flame retardant engineering thermoplastics are considerably expensive and generally stiff and unpliable.

A problem peculiar to radiating cables of the foam-dielectric type arises due to the very construction of such cables. In a radiating cable, slots or other apertures are provided in the outer conductor to allow a controlled portion of the transmitted RF signal to radiate, thus creating elemental radiating sources along the entire length of the cable. The outer conductor itself surrounds an assembly consisting of a foam core extruded onto an inner conductor. The entire coaxial assembly is then jacketed with a flame retardant material. With this type of construction, when the cable is subjected to high heat conditions in a fire, the foam inside the cable melts and bubbles out of the apertures in the outer conductor and can penetrate the softened external jacket so as to be exposed to the fire. Consequently, flames propagate rapidly along the cable and can lead to total destruction of the cable.

These problems have been avoided by an improved flame retardant radiating coaxial cable, as disclosed in U.S. Patent No. 4,800,351, issued to the present inventors, wherein a layer of highly flame retardant inner barrier tape is employed between the outer conductor and the external jacket of the cable. The tape is selected to be of a material having good thermal barrier properties while at the same time having a substantially low dielectric loss and good transmission properties so that the radiation field around the slots or apertures of the outer conductor is substantially unaffected by the barrier tape itself. The provision of the barrier tape effectively contains the foam dielectric inside the cable, thereby preventing the flammable foam from contributing to the fire. The combination of the flame retardant barrier tape and the flame retardant thermoplastic material of the jacket provides a highly flame retardant, yet non-toxic and pliable radiating cable.

A significant problem arises when flame retardant radiating cable of the above kind has to be adapted to also exhibit a high degree of resistance to water penetration. This is because the use of the flame-retardant barrier tape is incompatible with the use of flooding compound around the outer conductor for realizing moisture blocking. As explained in the aforementioned '351 patent, the flame-retardant barrier tape has to be disposed between the outer conductor and the external jacket of a coaxial cable in order to effectively contain the foam dielectric within the conductor. This is important in order that the tape completely cover the radiating apertures and prevent the dielectric from melting and bubbling into penetrating contact with the jacket material, particularly if the jacket softens appreciably under high heat conditions.

The above advantageous flame-retardant construction cannot be readily adapted if a flooding compound is used because adequate water-blocking capability is achieved only if the compound is disposed directly on the aperture outer conductor. It then becomes wholly impractical to wrap the flame-retardant tape over the coating of flooding compound. Further, the flooding compounds typically used for such coaxial cable applications are themselves inflammatory, at least to a certain degree, and, accordingly, counteract the flame retardance provided by the barrier tape.

SUMMARY OF THE INVENTION

It is a primary object of the invention to provide a radiating coaxial cable of the foam dielectric type with improved water-blocking characteristics.

In this regard, it is a related object of this invention to provide a highly water-resistant radiating cable which exhibits localized water absorption and restricted longitudinal water migration characteristics.

A further object of this invention is to provide a radiating cable with all the above characteristics which is economical and relatively simple to manufacture and which is conveniently stored and flexible in use.

Yet another object is to provide a radiating moisture-blocking cable of the above type which can easily be adapted to exhibit high fire-retardancy properties.

Other objects and advantages of this invention will become apparent from the following description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF TEE DRAWINGS

FIG. 1 is a cutaway view showing the various layers comprising a radiating coaxial cable according to the principles of this invention.

FIG. 2 is a cutaway view of a radiating coaxial cable according to an alternative embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the invention will be described in connection with certain preferred embodiments, it will be understood that it is not intended to limit the invention to these particular embodiments. On the contrary, it is intended to cover all alternatives, modifications and equivalent arrangements as may be included within the spirit and scope of this invention as defined by the appended claims.

As shown in FIG. 1, the radiating cable, generally designated by the numeral 10, comprises an inner conductor 11 at the center of the cable. The inner conductor 11 is generally of a smooth or corrugated conducting material such as copper, aluminum or copper-clad aluminum. The inner conductor 11 is surrounded by a layer of low-loss foam dielectric material 12 such as cellular polyethylene or the like. An outer conductor 13 surrounds the foam dielectric and is generally made from a corrugated copper strip which is provided with a series of slots or apertures 14 arranged along the axial length of the conductor. The slots are preferably oval in shape as shown in FIG 1, but they can also of be any other shape. The radiating apertures in the corrugated copper outer conductor permit a controlled portion of the radio frequency signals being propagated through the cable to radiate from elemental sources along its entire length so that the coaxial cable in effect functions as a continuous antenna. The construction described so far is conventional and commonly used for radiating cables. In such cables, the outer conductor 13 is provided with an external sheath or jacket 16 which is typically formed of a suitable thermoplastic material and serves as an external protective layer for the cable. Cables of this type have been rendered impervious to water by filling or flooding the spaces between the outer conductor 13 and the external jacket 16 by a water-blocking compound, typically petroleum jelly. The fabrication procedure involves the application of the flooding compound over the outer conductor through some form of pumping mechanism and subsequently extruding the outer jacket over the coated structure. The flooding compound is necessarily highly viscous and the pumping operation is difficult and messy.

In order to render radiating cables of this type water impervious while avoiding the above-discussed problems, at least one layer of moisture-blocking barrier tape 15 (see FIG. 1) is provided over the corrugated outer conductor 13. The external jacket 16 is then extruded over the barrier tape 15. In effect, the tape 15 functions as a moisture-or water-blocking barrier between the external jacket 16 and the outer conductor 13 whereby moisture or water is restricted from coming into contact with the conductor 16 and, more importantly, with the radiating slots 16 and the foam dielectric 12. Even if the integrity of the jacket is affected, for example, by mechanical cuts or tears thereupon, the barrier tape is adapted to restrict both radial and longitudinal penetration of water, thereby significantly reducing the susceptibility of the cable to changes in electrical properties due to the effects of water on the foam dielectric.

This approach is advantageous in that effective water blocking can be achieved without the need for any flooding compound. The barrier tape can be conveniently wrapped over the outer conductor as part of the standard cable manufacturing operations. The outer jacket is also conveniently extruded over the barrier tape. Also, such radiating cables can be easily cut and spliced since the layer of barrier tape can be easily severed and the cable ends re-connected conveniently.

The water-blocking barrier tape is preferably of the dynamic barrier type which is provided with a coating of water-swellable material between the core and the outer screen layer on the tape. The coating material has a high swell response to water and swel ls appreciably upon contact with the water. As a result, virtually all capillary spaces and interstices between the core and screen are sealed off, thereby restricting both radial and longitudinal penetration of water. In effect, the area between the outer conductor 13 and the external jacket 16 is sealed off when water contacts the barrier tape disposed therein.

The coating material is typically in the form of a powder formed of a natural water-absorbent material such as cellulose, or synthetic water-swellable polymeric materials such as sodium polyacrylates.

Preferred characteristic properties required of the barrier tape include adequate swelling height, swelling speed, and gel strength so as to effectively localize water ingress and provide a steady water penetration depth. The swellable powder should be bonded firmly within the tape (i.e., within the core and screen layers thereof) so that dusting is minimized during cable manufacturing, terminating or splicing. The firm bonding also ensures uniform powder distribution over cable circumference and length. It is important that the barrier tape be capable of adequate swelling and water retention over repeated wet/dry cycles.

In terms of physical properties, it is desirable that the barrier tape possess sufficient mechanical strength and flexibility to allow easy application and avoid impairing the overall cable flexibility. The surface of the screen on the tape side which is exposed to water is preferably of an open-structured fabric in order to facilitate access of water to the underlying water-swellable powder. In terms of its chemical properties, the barrier tape is preferably insulating or, at least, semi-conductive with a low volume resistivity.

Water-blocking tapes satisfying most of the above specifications are commercially available under the trade names "K-Block" and "FIRET" from Kable Tapes Ltd. of Indiana, USA and Lantor Bv. of Holland, respectively. The "K-Block" tapes use natural, cellulose-based powder for the water absorbent layer. The FIRET tapes, on the other hand, use an absorbent layer formed of a synthetic material. For long term use, tapes with synthetic polymeric coatings are preferred since such coatings are not susceptible to degradation due to bacterial and mildew attacks.

The manufacturing process involved in producing a water resistant radiating cable according to this invention, includes the initial step of extruding the foam dielectric core 12 (see FIG. 1) onto an accurately and appropriately sized inner conductor 11 normally made of copper. Subsequently, strip stock of the desired material, generally copper or aluminum, is formed into a tube around the previous assembly and then welded to form the continuous outer conductor 13. The outer conductor is arranged to be coaxial with the inner conductor 11 with the foam dielectric filling substantially the entire interior of the outer conductor other than the inner conductor. The outer conductor is annularly or helically corrugated (to provide cable flexibility) with any longitudinal sections thereof having alternating crests 3A and troughs 3B and the radiation apertures 14 are disposed on the crests. The above arrangement results in the material of the outer conductor 13 biting into the dielectric core in the vicinity of the corrugated troughs 3B and insures sufficient gripping action between the outer conductor and the dielectric it surrounds while being capable of accommodating differential expansion between the two. The strip of metal forming the outer conductor may contain the radiating apertures 14 of the desired shape and size before being formed and corrugated around the core assembly. Alternatively, the outer conductor may be positioned around the core assembly and corrugated before milling the radiating apertures thereupon.

At this stage, the water-blocking barrier tape 15 is wrapped around the outer conductor 13 in such a way that all the radiating apertures 14 are completely covered by the barrier tape. This wrapping is preferably performed with a fifty percent (50%) overlap so that a double layer of barrier tape is effectively provided over the radiating apertures 14. The entire assembly is subsequently jacketed by extruding the desired protective thermoplastic material 16 over it.

The provision of the barrier tape constitutes a simple additional step in the overall cable manufacturing process. Since the tape is flexible and easily pliable it can be conveniently wrapped over the outer conductor. The flexible nature of the tape also insures that flexibility of the overall cable assembly is retained. Depending on the actual application, virtually any mechanically sturdy polymeric material can be used for forming the external jacket 16. For flame retardant cables, however, it is preferable that the external jacket material be flame-retardant non-halogenated, self-extinguishing and of low dielectric loss. These properties are particularly advantageous in radiating cables. Jacket material possessing the above characteristics is commercially available from the General Electric Company under the tradename "NORYL-PX 1766".

In conventional radiating cables, the outer jacket provided over the outer copper conductor itself is flame retardant. When such cables are subjected to extreme heat conditions, the jacket material, in spite of being flame retardant, softens at higher temperatures. In addition, the foam dielectric material 12 contained by the outer conductor melts at higher temperatures and as the temperature continues rising the melted foam bubbles outside the confines of the outer conductor 13 through the radiating apertures 14. The bubbling dielectric is forced against the softened outer jacket and eventually penetrates it to be exposed directly to the fire; the dielectric material feeds the fire and freely propagates flames, eventually leading to complete destruction of the cable.

One exemplary approach to improving the fire retardancy of a radiating coaxial cable has been the provision of a layer of inert, flame retardant barrier tape over the corrugated outer conductor, as described in the aforementioned '351 patent. An external sheath or jacket made of a flame retardant non-halogenated thermo-plastic material is then provided over the barrier tape. The tape functions as a barrier between the external jacket and the outer conductor by virtue of which the foam dielectric is efficiently contained within the conductor and prevented from melting and bubbling out into contact with the jacket material. Even if the material of the outer jacket softens appreciably under high heat conditions, there is no possibility of bubbling foam penetrating the jacket.

As disclosed in the '351 patent, the barrier tape is selected to be of a composition which is capable of serving as an insulating barrier even when exposed to flames with a substantially high temperature. The tape composition is chemically inert, non-toxic and contains no halogenated substances. The composition is also preferably impervious to water, radiation resistant, acid-resistant and alkaline-resistant. It is also necessary that the barrier tape have good tensile strength, in addition to being dry, nontacky, flexible and sufficiently applicable. A preferred composition for the barrier tape comprises an inorganic refractory material such as electric grade mica, which is impregnated with a heat resistant binder and combined with a suitable carrier material such as fiberglass. It is important that the refactory material display a suitable low dissipation factor when used in the cable at the frequencies at which radiating co-axial cables commonly operate. This ensures that the presence of the barrier tape does not significantly affect the electrical characteristics of the cable. Tapes satisfying the above specifications are commercially available under the trade name "FIROX" from Cogebi of Belgium.

However, this advantageous technique of using the flame-retardant barrier tape is incompatible with the conventional approach of using flooding compounds for imparting water-blocking properties to radiating coaxial cables. As described above, the flooding compound is coated upon the outer conductor of the cable by some form of pumping mechanism, yielding a greasy layer. It becomes extremely difficult and messy to wrap the layer of flame-retardant tape over the greasy layer of the flooding compound. Because of the absence of a frictional surface underneath the tape, the gripping action necessary for initially wrapping the tape according to a desired configuration, and subsequently for retaining the wrapped tape, is totally absent. Consequently, the water-blocking tape becomes easily susceptible to slippage both during and after wrapping, thereby defeating the purpose of covering the radiating slots in a watertight fashion. As a result, the combination of the flooding compound and the flame-retardant barrier tape is impractical.

The construction shown above in FIG. 1, in accordance with the principles of this invention, is particularly adapted to be used in conjunction with the flame-retardant barrier tape, thereby rendering practical the design and construction of a radiating coaxial cable of the foam dielectric type which is both moisture-blocking and flame-retardant to a high degree. After the water-blocking barrier tape has been wrapped over the outer conductor, the fire-retardant barrier can be wrapped there over in an identical fashion. The combination is advantageous in that the water-blocking tape does not contribute in any way to flame propagation and the flame-retardant tape does not compromise the water-blocking properties of the cable.

An arrangement of this type is illustrated in FIG. 2 in accordance with an alternative embodiment of this invention. The embodiment of FIG. 2 is similar to the one disclosed in FIG 1 except for the provision of a layer of flame-retardant barrier tape 17 wrapped over the layer of water-blocking tape 15 which is wound directly over the outer conductor 13. The second layer 17 is preferably wrapped with a 50% overlap. The layer 17 functions to supplement the action of the primary layer 15 in sealing the radiating apertures 14. More importantly, the layer 17 imparts flame retardancy without substantially affecting the water-blocking properties, the transmission properties or flexibility of the cable.

Radiating cable samples constructed, as described above, using the combined layers of water-blocking tape and flame-retardant tape, have been successfully tested both for their flame spread characteristics under the UL 1581/IEEE 383 Vertical Tray Flame Test Protocols (UL 1581, *Reference Standard For Electrical Wires, Cables And Flexible Cords*, Underwriters Laboratories Inc., Northbrook, Illinois, U.S.A., 1983; IEEE 383-1974, *Standard For Type Test Of Class 1E Electrical Cables, Field Splices, And Connections For Nuclear Power Generating Stations*, Institute Of Electrical & Electronics Engineers, New York, U.S.A., 1974) and their water penetration characteristics under the Rural Electrification Agency Test Protocol (REA; PE-39, Section 28).

From the foregoing, it is apparent that the applicants' invention provides a radiating cable of the foam dielectric type with significantly improved water-blocking characteristics without the many problems typically associated with the use of flooding compounds. In addition, such cables can be adapted conveniently to exhibit high flame retardancy without the accompanying loss of economy or degradation in electrical characteristics that results from the conventional use of cross-linked polymer material for the dielectric layer and/or the protective external jacket. Radiating cables formed in accordance with this invention exhibit a high degree of water-blocking, restricted radial and longitudinal water migration, do not propagate flames, are easily manufactured according to conventional procedures, and are conveniently installed by virtue of their superior flexibility.

Claims

1. A radiating coaxial electric cable of the foam dielectric type which has improved water-blocking characteristics, said cable comprising:
an inner conductor;
a layer of cellular foam dielectric material surrounding the inner conductor;
a single, continuous, corrugated outer conductor surrounding the dielectric foam layer in direct contact therewith, said outer conductor having apertures disposed on the crests of the corrugations in said outer conductor along its length for the passage of electromagnetic radiation;
at least one layer of water-blocking barrier tape

wrapped over the outer surface of the outer conductor so as to cover each of said radiating apertures of said outer conductor, said barrier tape comprising a layer of water-swellable material adapted to swell in contact with water so as to effectively retain the contacting water within a localized area, said tape functioning as an absorbent barrier for absorbing any water or moisture penetrating said extruded jacket and restricting radial and longitudinal migration of said absorbed water or moisture; and
a protective outer jacket extruded over the wrapped layer of tape.

2. The radiating cable of claim 1 wherein the water-blocking barrier tape includes a layer of water-swellable natural polymeric material, such as cellulose powder.

3. The radiating cable of claim 1 wherein the water-blocking barrier tape includes a layer of water-swellable synthetic polymeric material such as sodium polyacrylate.

4. The radiating cable as set forth in claim 1 wherein a layer of flame-retardant tape is wrapped over said layer of water-blocking barrier tape so as to effectively cover said radiating apertures, said barrier tape comprising a particulate refractory material affixed by a heat-resistant binder to a carrier material.

5. The radiating cable of claim 4 wherein the refractory material on said flame-retardant tape is dielectric grade mica and the selected carrier material is fiberglass.

6. In a radiating coaxial cable comprising an inner conductor, a layer of cellular foam dielectric material surrounding the inner conductor, a single, continuous, corrugated outer conductor surrounding the layer of foam dielectric and including radiating apertures disposed the crests of the corrugations in said outer conductor along its length, the troughs of the corrugations of said outer conductor biting into the dielectric layer so as to restrict relative longitudinal displacement between the outer conductor and the dielectric layer, and an external jacket surrounding the outer conductor, the improvement comprising the provision of at least one layer of water-blocking barrier tape, wrapped over the outer surface of the outer conductor in such a way as to cover all radiating apertures defined thereupon, said barrier tape comprising a layer of water-swellable material adapted to swell in contact with water so as to effectively retain the contacting water within a localized area, said tape functioning as an absorbent barrier for absorbing any water or moisture penetrating said extruded jacket and restricting radial and longitudinal migration of said absorbed water or moisture.

7. The radiating cable of claim 6 wherein the water-blocking barrier tape comprises a layer of water-swellable natural material, such as cellulose powder.

8. The radiating cable of claim 6 wherein the water-blocking barrier tape includes a layer of water-swellable synthetic polymeric material, such as sodium polyacrylate.

9. The improved radiating cable of claim 6 wherein a layer of flame-retardant tape is wrapped over said layer of water-blocking tape so as to effectively cover said radiating apertures.

10. The improved radiating cable of claim 6 wherein said flame-retardant tape is composed of an inorganic refractory material such as electric-grade mica which is impregnated with a heat-resistant binder and combined with a carrier material such as fiberglass.

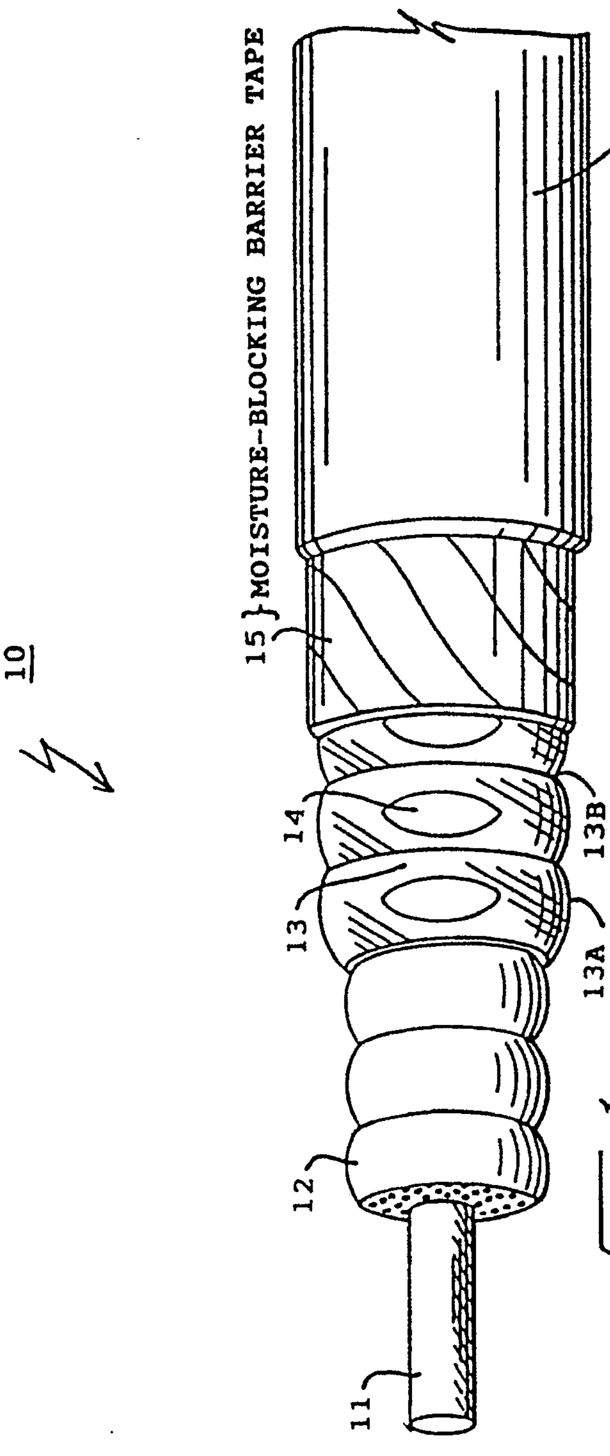
10
MOISTURE-BLOCKING BARRIER TAPE
15
16
14
13
13A
13B
12
11

Fig. 1.

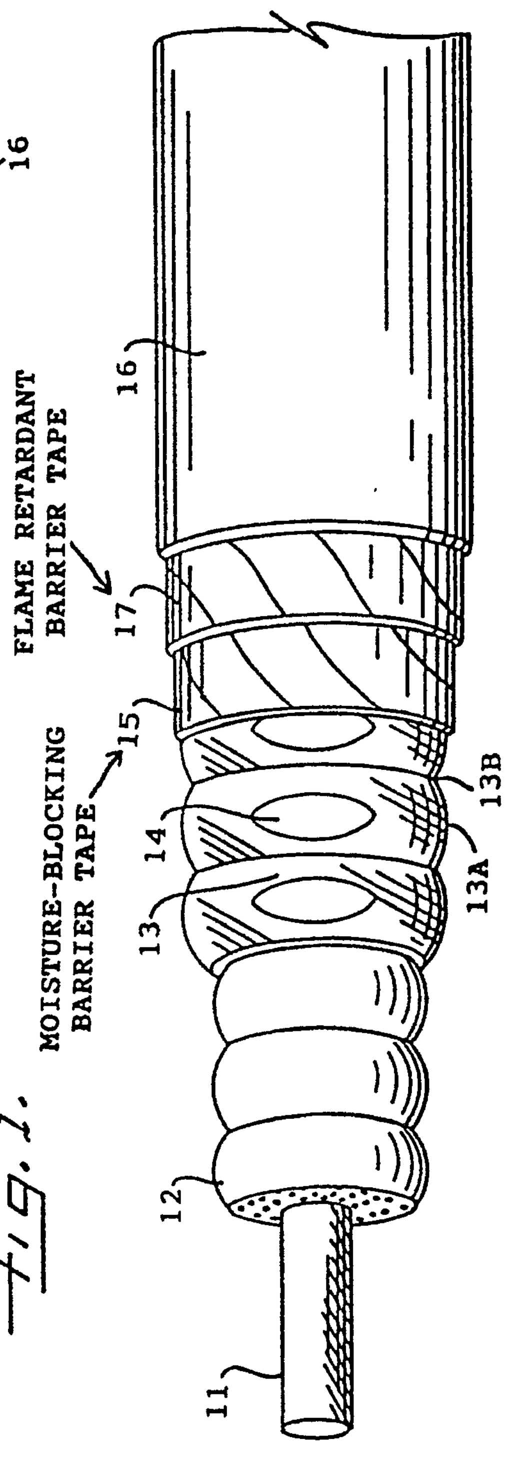
FLAME RETARDANT
BARRIER TAPE
MOISTURE-BLOCKING
BARRIER TAPE
17
15
16
14
13
13A
13B
12
11

Fig. 2.